

**Engineering
Cost
Office**

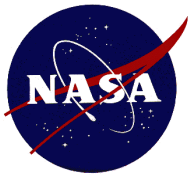
Crewed and Space Transportation Systems Cost Model

CASTS

NASA Cost Symposium
August 25-27, 2015

Presented by:
Andy Prince – NASA MSFC
and
Richard Webb – KAR Enterprises





Crewed and Space Transportation Systems Cost Model

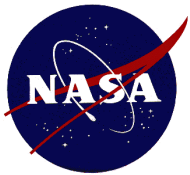
OUTLINE



**Engineering
Cost
Office**

- **CASTS – Where it is today**
 - Model Development Process
 - Historical Database
 - Estimating Approach
 - Example
 - Results/Observations
- **NEXT STEPS – Work in process**
 - Virtual Black Books
 - Functional Breakdown Structure
 - CER Updates
 - Full Life Cycle Cost Capability



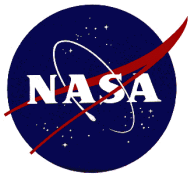


Overall Goals



- **Philosophical framework**
 - Develop a new, unique cost model for use in estimating space transportation systems, including crewed systems, and earth-to-orbit and in-space transportation systems.
 - Based on historical database consisting exclusively of transportation/crew systems
 - *Credible, Supportable, Defendable* estimates
- **Initial Emphasis: Basis of Estimate**
 - Traceability and transparency of estimate to database
 - Development and documentation of the database and analytical processes behind the CERs incorporated in the model
 - Provide flexibility to use CASTS data/model as point-of-departure for tailored/customized estimates



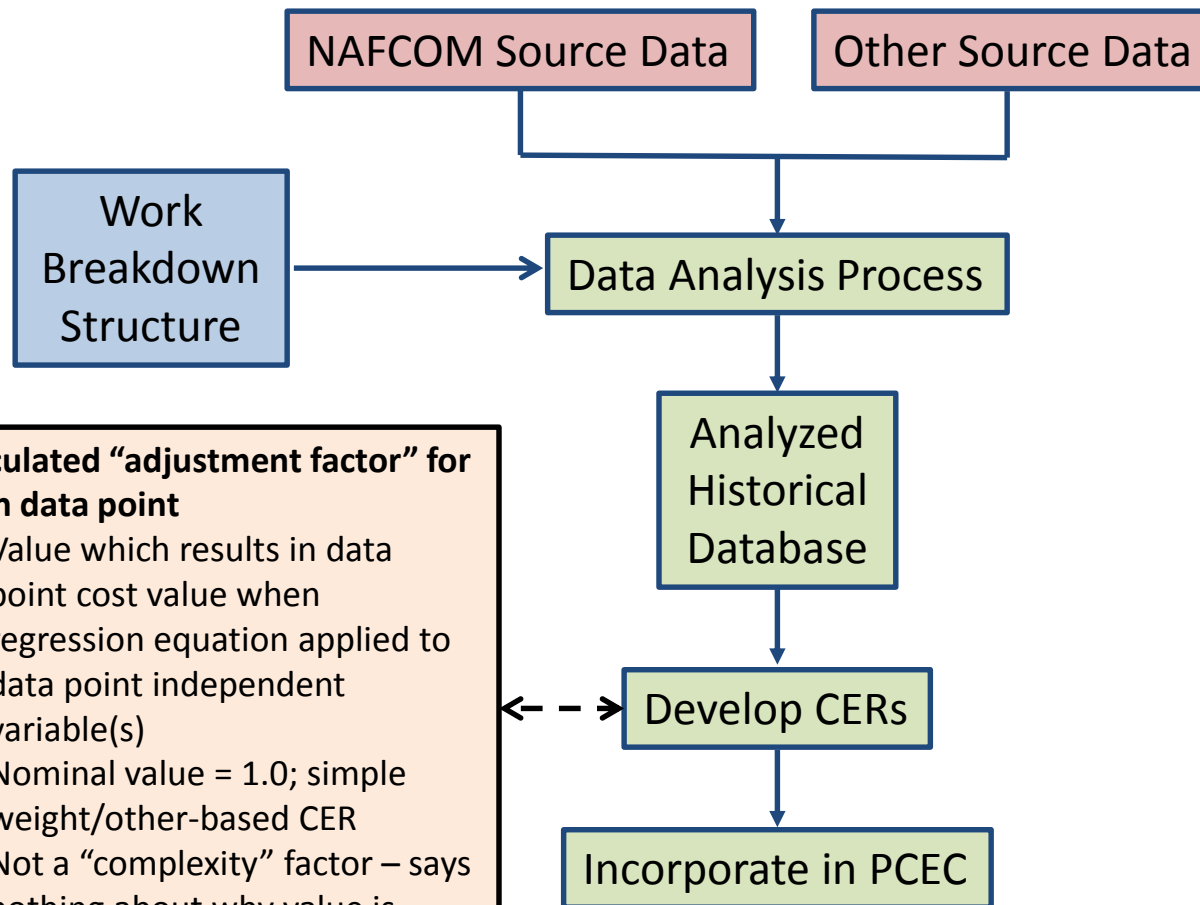


Crewed and Space Transportation Systems Cost Model Model Development Process



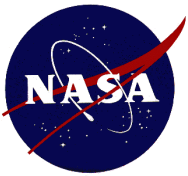
Engineering
Cost
Office

- CASTS development process



- Calculated “adjustment factor” for each data point
 - Value which results in data point cost value when regression equation applied to data point independent variable(s)
 - Nominal value = 1.0; simple weight/other-based CER
 - Not a “complexity” factor – says nothing about why value is what it is





Crewed and Space Transportation Systems Cost Model Historical Database



Engineering
Cost
Office

- **Reconstituting Historical Database has been primary focus to date**
 - NAFCOM heritage: trace back to source documents
 - New systems: Develop suitability for inclusion in database
 - DOCUMENTATION – from sources to CERs
 - Analysis spreadsheets, references

Roster of systems currently included in CASTS CER datasets

Launch Vehicles

Atlas V Common Core Booster
Atlas V Centaur
Apollo Command/Service Module
Apollo Lunar Module
Centaur D
Centaur G' (Shuttle Centaur)
Centaur G' CISS - ASE
Shuttle External Tank
Shuttle Orbiter
Shuttle Solid Rocket Motor
Shuttle Solid Rocket Booster
Saturn V 1st Stage (SIC)
Saturn V 2nd Stage (SII)
Saturn V 3rd Stage (SIVB)
Titan Centaur
Titan IV 5m Fairing
Atlas I, II, IIA, IIAS
Super Lightweight External Tank

Liquid Engines

F1
J2
J2X
RS27
RD180
RL10
RS68
SSME

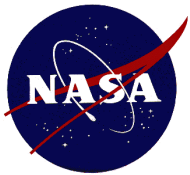
Solids

Titan IV SRMU
Athena Castor 120
Trident D5
Shuttle RSRM
Atlas IIAS Castor 4A
Atlas V SRM
Ariane V EAP-P230
Pegasus

Software

SSME Adv Health Mgt Sys
Orbiter Cockpit Avionics Upgrade
Orbiter Primary Avionics Software Sys
Orbiter Backup Flight Software
BRAHMS
DART
X33
Centaur G'
Atlas II
Atlas V





Crewed and Space Transportation Systems Cost Model

Work Breakdown Structure

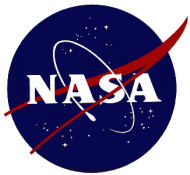


**Engineering
Cost
Office**

- CASTS - Work Breakdown Structure**

Program Segment		Vehicle Segment (cont'd)		Vehicle Segment (cont'd)	
	Program Mgt & Support		Mechanisms		Avionics & Power
	Systems Engr & Integ		Thrust Vector/Flight Control		Guidance, Nav, & Control
Vehicle Segment			Separation		Telemetry & Tracking
	Integration, Ass'y, Checkout		Recovery		Command, Ctl, Data Handling
	Crew Structures		Other		Range Safety/Flt Termination
	Wing		Main Propulsion Systems		Electric Power
	Tail		Thermal Protection		Shroud/Fairing
	Fuselage/Body		Passive		Crew Systems
	Capsule Structures		Re-Entry Leading Edges		Environ Ctl & Life Supt
	Thrust Structure		Re-Entry Heat Shield		Displays/Controls
	Adapters		Propulsion	Software Segment	
	Secondary/Support Structs		Liquid Engines		Flight Software
	Tanks		Solid Motors		Ground Software
	Intertank		Reaction Ctl/Orb Maneuv Sys	Test Segment	
					System Test Operations
					System Test Hardware
				Ground Segment	
					Ground/Test Support Equip
					Tooling





Crewed and Space Transportation Systems Cost Model

CERs by WBS Element



**Engineering
Cost
Office**

- Work Breakdown Structure – Cost Estimating Relationships**

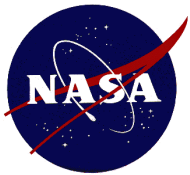
Program Segment	
	Program Mgt & Support
	Systems Engr & Integ
Vehicle Segment	
	Integration, Ass'y, Checkout
	Crew Structures
	Wing
	Tail
	Fuselage/Body
	Capsule Structures
	Thrust Structure
	Adapters
	Secondary/Support Structs
	Tanks
	Intertank

Vehicle Segment (cont'd)	
	Mechanisms
	Thrust Vector/Flight Control
	Separation
	Recovery
	Other
	Main Propulsion Systems
	Thermal Protection
	Passive
	Re-Entry Leading Edges
	Re-Entry Heat Shield
	Propulsion
	Liquid Engines
	Solid Motors
	Reaction Ctl/Orb Maneuv Sys

Vehicle Segment (cont'd)	
	Avionics & Power
	Guidance, Nav, & Control
	Telemetry & Tracking
	Command, Ctl, Data Handling
	Range Safety/Flt Termination
	Electric Power
	Shroud/Fairing
	Crew Systems
	Environ Ctl & Life Supt
	Displays/Controls
Software Segment	
	Flight Software
	Ground Software
Test Segment	
	System Test Operations
	System Test Hardware
Ground Segment	
	Ground/Test Support Equip
	Tooling

CER Type
Cost-to-Cost
Des & Dev + Flt Unit (wt/other)
Adjustment Factor
Multi Var CER (DD & FU)





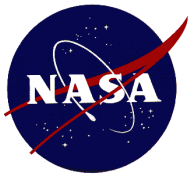
Crewed and Space Transportation Systems Cost Model Estimating Approach



**Engineering
Cost
Office**

- **Why this approach?**
 - Significant data “clutter”
 - Minimal number data points with multiple potential variables
 - Lack of/dissimilar definitions between sources
 - Poor predictive value (P-values $\gg .05$)
 - Counter intuitive results (cost $>$ over time, cost $<$ increased complexity)
 - Conflicting/countervailing influences between potential variables
 - Time vs. degree of new design vs. technology level vs. SOA vs. etc.
 - Calculated “adjustment factor” for each data point
 - Not a “complexity” factor – says nothing about why value is what it is
 - Not the “final answer” (see Next Steps)





Example CASTS CER

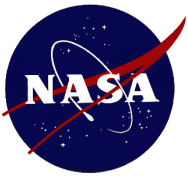


• CASTS CER Inputs/Process/Outputs Example – Thrust Structure

- Inputs: 30,000 lbs, in-line, multiple engines, AI 2219, extensive test program (“man-rateable”), constant 2015 \$ (mil), 20 production units at rate of 4 per year, fabricated in-house by prime contractor (e.g. MAF)
- Process:
 1. Thrust Structure CER
 - $D\&D\$ = .1160 \times wt^{.6693} \times \text{adjustment factor}$
 - $FU\$ = .0079 \times wt^{.8121} \times \text{adjustment factor}$
 - Large (SIC = 55Klb, SII = 7Klb, ET = n/a), in-line, new design, multiple engines
 - Use SIC DD (1.1271) and FU (.7795) adjustment factors

Subsystem Adjustment Factors						
Include?	Subsystem	Sub-Group	Mission	WBS Item	D&D Factor	Flt Unit Factor
	Thrust Structure		SIVB	Thrust Structure	1.48	1.34
x	Thrust Structure		SIC	Thrust Structure	1.13	0.78
	Thrust Structure		SII	thrust struct	1.09	1.57
	Thrust Structure		AV CCB	Aft Transition	0.62	0.76
	Thrust Structure		C-D	Thrust	0.90	0.80





Crewed and Space Transportation Systems Cost Model

Example CASTS CER



Engineering
Cost
Office

- CASTS CER Inputs/Process/Outputs

- System Test Hardware

- Use CER (vs. standard 1.30 factor) = $2.313 \times \text{FU}^{\text{\$}^{.9679}}$

- For Production Cost - assume 90% Crawford learning curve (typical); 65% rate curve (ET \approx 60%)

- Outputs:

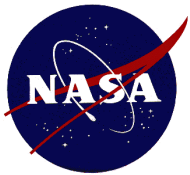
Estimate Summary						
	DDT&E	Design & Development	System Test Hardware	Flight Unit	Production	TOTAL
FY2015 \$M	\$ 185.90	\$ 129.86	\$ 56.04	\$ 26.92	\$ 164.98	\$ 350.89

$$\text{D\&D} = \$129.9 = .1160 \times 30,000^{.6693} \times 1.127$$

$$\text{FU} = \$26.9 = .0079 \times 30,000^{.8121} \times .7795$$

$$\text{STH} = \$56.0 = 2.313 \times 26.9^{.9679} \times 1.000$$





Crewed and Space Transportation Systems Cost Model

Example CASTS CER



**Engineering
Cost
Office**

• CASTS CER Inputs/Process/Outputs

• Outputs (cont'd):

Estimate Summary						
	DDT&E	Design & Development	System Test Hardware	Flight Unit	Production	TOTAL
FY2015 \$M	\$ 185.90	\$ 129.86	\$ 56.04	\$ 26.92	\$ 164.98	\$ 350.89

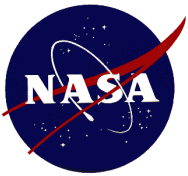
Production Cost Calculation						
FY2015 \$M						
Yr. No.	Cumulative Units	Learning Curve Effects	Production Quantity/Year	Recurring Production Cost/Year	Fixed/Variable Production Estimate/Year	Diff: RC vs. F/V
1	4	\$ 95.28	4	\$ 40.25	\$ 31.78	1.267
2	8	\$ 80.62	4	\$ 34.06	\$ 31.78	1.072
3	12	\$ 74.81	4	\$ 31.61	\$ 31.78	0.995
4	16	\$ 71.20	4	\$ 30.08	\$ 31.78	0.947
5	20	\$ 68.59	4	\$ 28.98	\$ 31.78	0.912
6	20	\$ -	0	\$ -	\$ -	0.000
7	20	\$ -	0	\$ -	\$ -	0.000
8	20	\$ -	0	\$ -	\$ -	0.000
9	20	\$ -	0	\$ -	\$ -	0.000
10	20	\$ -	0	\$ -	\$ -	0.000
TOTAL			20	\$ 165.0	\$ 158.9	

Fixed/Variable Calculation

FY2015 \$M	
T1,1	\$ 30.79
Variable Cost per Unit	\$ 2.42
Fixed Cost per Year	\$ 22.10
Cumulative Diff	\$ (6.11)
% Diff	-3.7%

Average Cost per Unit
\$ 8.249





Crewed and Space Transportation Systems Cost Model

Example CASTS CER



**Engineering
Cost
Office**

• CASTS Example Analyses

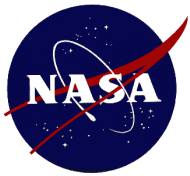
• Sensitivity Analyses:

- Questions: How does unit and total production cost change if...
 1. We fly 1 more flight per year? 2?
 2. We fly 20 flights in 7 years? 28?
- Process:
 - Change total production units and flights/year
- Answers:
 1. +\$9M Total, -\$1.3M AUC; +\$17M Total, -\$2.2M AUC
 2. +\$37M Total, +\$1.8M AUC; +\$55M Total, -\$1.4M AUC

Years Ops:	5		
Rate Curve:	65%		
Flts/Year	4	5	6
Total Flights	20	25	30
Total Prod \$	\$ 165.0	\$ 174.1	\$ 181.9
Avg Unit \$	\$ 8.25	\$ 6.96	\$ 6.06
Var CPF	\$ 2.42	\$ 2.35	\$ 2.29
Fixed CPY	\$ 22.10	\$ 21.44	\$ 20.90

Years Ops:	7	
Rate Curve:	65%	
Flts/Year	3	4
Total Flights	20	28
Total Prod \$	\$ 202.2	\$ 220.5
Avg Unit \$	\$ 10.11	\$ 7.88
Var CPF	\$ 2.48	\$ 2.31
Fixed CPY	\$ 22.65	\$ 21.10





Results/Observations



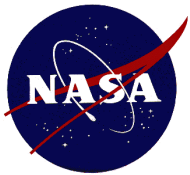
- **Initial results**

- Ran SLS Core stage through PCEC using CASTS CERs
 - Did not use any adjustment factors – all = 1.0
 - Result was less than 5% different than PRICE-based estimate
 - At top level; comparison at lower levels still to-do

- **Observations relative to CASTS development effort to date**

- Data
 - Each point is important – need to understand each one as much as possible – drive back to source documentation
 - Significant amount of data clutter between sources
 - Different/inconsistent definitions, accounting methods, etc.
- Independent Variables
 - Each datapoint is unique mix of potential independent variables
 - Time, complexity, inheritance, system evolution, SOA, materials, processes, configuration/definition, etc.





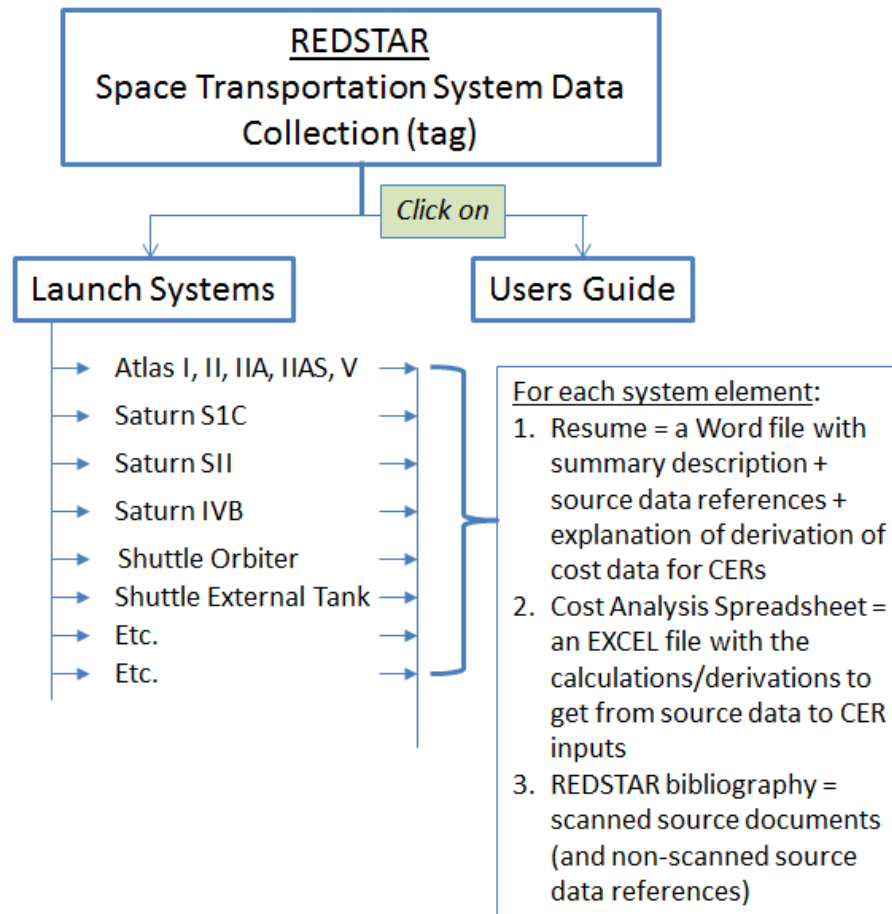
Crewed and Space Transportation Systems Cost Model

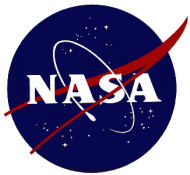
Next Steps – Work In Process



Engineering
Cost
Office

- **Virtual Black Books**
 - CADRE-like – not a CADRE, but same type of information
 - Will be available online through REDSTAR





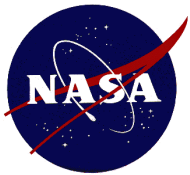
CASTS – Next Steps



- **Functional Breakdown Structure**

- Cost delineated by functions (Engineering, Touch, Manufacturing Support, Quality Assurance, etc.) rather than end items (weight, thrust, lines of code, etc.)
- Much historical data is in this format; not always by end item
- Many (most?) cost reduction/affordability approaches relate most directly to functions, not end items
 - E.g. Touch labor vs. automated welding; SR&QA vs. reduction in Gov't Mandated Inspection Points (GMIPS); Facility O&M vs. shared facilities
- Schedule tasks usually address functions directly, not end items
 - E.g. “design”, “analyze”, “test”, “fabricate”, “inspect”, etc.
- FBS capability will allow more visibility/flexibility regarding estimates of (for instance):
 - Potential cost/savings of affordability initiatives
 - Integration of parametric-based estimates with JCL schedules





CASTS – Next Steps



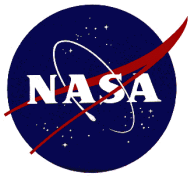
- **CER Updates**

- Expand historical database/incorporate in CERs
- Explore meaningful independent variables
 - Replace Adjustment Factors
- Investigate development of objective Complexity Generators

- **Full Life Cycle Cost Capability**

- Time dimension - Full life cycle cost estimating capability: “sand charts”
 - Spread vs. non-spread cost
 - Cost as function of flight/production rates over time
 - (Capability) Nonrecurring facilities, mission and launch ops





CASTS – Summary



- **Model and data: Traceability and transparency**
 - Substantial progress made in reviewing, updating, and understanding the crewed and space transportation systems' historical database.
 - Documentation of the historical database provides a detailed but easy-to-use resource for NASA cost analysts to better understand the database itself and, as a result, provides a better basis of estimate for future estimates.
- **Estimating capability: Depth and breadth**
 - The initial set of CASTS CERs released with PCEC ver. 2.0, when coupled with the accompanying documentation, provide a set of estimating alternatives that cover the breadth of end items that comprise crewed and space transportation systems and a depth of understanding of the historical database upon which the estimate is based.

Credible, Supportable, Defendable

